Volume 19 January, 1933 *Number 1*

Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

Diesel Engine
Lubrication Economy

PUBLISHED BY
THE TEXAS COMPANY
TEXACO PETROLEUM PRODUCTS

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Published by

The Texas Company, 135 East 42nd Street, New York City

Vol. XIX | January, 1933 | No. 1

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Diesel Engine Lubrication Economy

DURABILITY or extended life, as it may apply to the Diesel engine, is a popular topic at any time. Today it is of particular importance to Diesel plant operators, who must frequently carry on at considerably reduced revenue. Factors which may bear a direct relation to engine life likewise require consideration. Paramount among these is lubrication, especially since it is the controlling protective element in engine operation. Lubrication, however, is not time-enduring, for lubricants, too, have a period of useful life, although this latter may be very indefinite, dependent upon the severity of service to which any particular oil is exposed. Many operators will be prone to expect too much from their lubricating oils, little realizing that their lubricating value may markedly affect the useful life of the engines in which they are employed.

Inasmuch as there are a number of factors which may affect the useful life of the oil, in turn, these must be thoroughly understood, for they will indicate when the oil should be changed, or, in other words, when it has temporarily functioned over the span of its useful life. It is not practicable for the Diesel operator arbitrarily to select a definite time during operation for changing oil, as is the custom in automotive engine service, for there are too many prevailing variables.

Study of these latter as they may apply to the two basic types of engines, viz., the two-cycle and the four-cycle type, will materially facilitate judgment as to when an oil should be changed.

FACTORS AFFECTING OIL CONSUMPTION

Lubricating oil consumption in Diesel engine service will be influenced by:

The possibility of contamination

The operating temperatures

The extent to which losses by leakage, agitation and aeration occur

Engine design and oil pressure

Broadly speaking, change of oil will be advisable when contamination in the circulating system has progressed to such a degree as to render the oil incapable of developing and maintaining a dependable lubricating film. Those substances which would tend to contaminate such an oil include water, fuel oil, dust and dirt, silica, iron oxides and carbon residue. The rate of accumulation can be determined only by periodic laboratory analysis.

Water will have a material effect upon the formation of both sludge and iron oxides. In turn, these latter will tend to promote formation of permanent emulsions which would lead to the development of insoluble sludge. While this latter might not always be abrasive, it would tend to accumulate in oil grooves and distributing piping, to reduce flow of oil to the bearings. Obviously any contamination as mentioned above would affect only crankcase oils or oils which are passed through the engine by an external circulating system.

Where cylinders receive their lubrication from a mechanical force-feed lubricator the oils are used only once. On the other hand, in

trunk types engines, where the base of the cylinders are open to the crankcase, any increase in temperature in this latter might require increase in the rate of oil feed to the cylinders.

Another factor which must be given consideration, particularly in engines of the splash lubricated type, is the matter of agitation and aeration, according to the prevailing temperature. In the crankcase aeration might lead to considerable loss of oil, with the formation of objectionable oily accumulations on the outside of the engine.

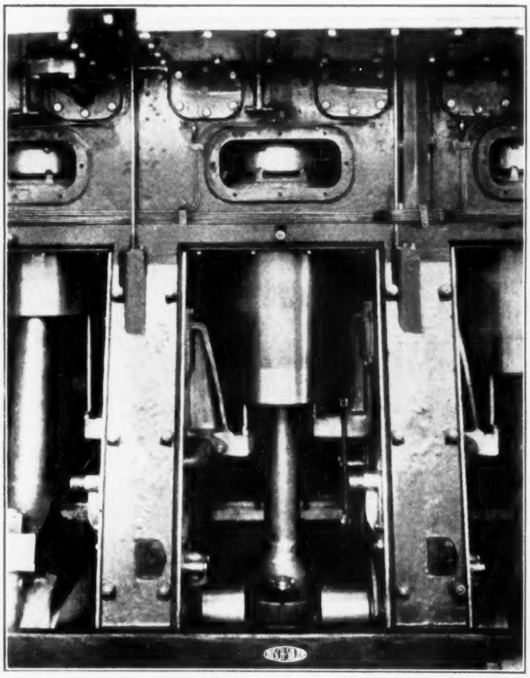
There have been instances in extreme conditions of the above nature, where marked discoloration of the walls of the engine room has developed. Reduction in the oil level will oftentimes overcome this fault and reduce agitation and aeration. It is, of course, more easy to control lubrication in the crosshead type engine where oil is pressure circulated. In an engine of this latter type the possibility of loss of crankcase oils through blow-by past the piston will also be eliminated. Furthermore, the temperature in the crankcase will generally be lower.

ENGINE DESIGN

In a study of lubricating oil economy and durability, constructional and operating conditions must be carefully considered, for service in a four-cycle engine is quite different from that in a two-cycle. Whether or not an engine is of the trunk or crosshead type is also an influencing factor. In other words, crankcase oil in a two-cycle trunk type engine is subjected to far more severe operation than in a four-cycle crosshead engine. The two-cycle engine is prone to run warmer, thereby to give rise to greater loss of oil through vaporization, particularly where the crankcase is a component part of the cylinders and exposed to the pistons. Furthermore, in engines of this latter type, oil contamination will be more likely to occur, all of which will reduce the useful lubricating life of any oil.

Cycle Requirements

The influence of engine design, temperatures and pressures and their effect upon maintenance of lubrication must be thoroughly understood. Cylinder lubrication in both the two and four-cycle engine can normally be accomplished by oils of similar characteristics, provided due consideration is given to low carbon residue content, and adequate viscosity to meet operating pressures and temperatures. Oil consumption in the two-cycle engine will normally be higher than in a four-cycle of the same cylinder size, in view of the location of the scavenging and exhaust ports, the somewhat higher temperatures, and the fact that a certain amount of oil will usually be scraped off from the piston and rings while passing these ports. Should an excessive rate of oil feed be inaugurated in order to compensate for this potential loss, abnormal deposits might develop in the scavenging air and exhaust ports.



Courtesy of Busch-Sulzer Bros.-Diesel Engine Co.

Fig. 1 —Showing crankcase accessibility in the Busch-Sulzer two-cycle trunk piston engine. Pistons are under constant observation by the operator. Installation of scraper rings leads lubricating oil to crankcase on the upstroke of the piston.

In the two-cycle Diesel, cylinder oil is also subjected to high temperatures at more frequent intervals over each cycle. By reason of the high velocity of the gases of combustion at the exhaust ports, the tendency toward vaporization of the lubricant is increased at this part of the cylinder. To reduce this effect an oil of lower volatility could be used, but the probable result would be an increase in carbonaceous residue formation.

The four-cycle engine does not develop the same amount of heat during operation, nor is the lubricant on the cylinder walls subjected to the same high velocity and vaporizing action of the exhaust gases as in the two-cyle type. This is explained by the absence of exhaust ports, the gases being discharged in a straight line direction through the exhaust valves in the cylinder heads. While the normal difference in temperature between engines of the four-cycle and two-cycle types is not great enough to require individual consideration in connection with cylinder lubrication, it must be re-

membered that the higher the temperature the greater may be the oil consumption.

Pressure and its relation to formation of an oil film is also important in the four-cycle engine, as the pressure on the moving parts is not always of the same intensity. For this reason, it may be difficult for the lubricating oil to spread uniformly over cylinder liner surfaces when the piston rings are under pressure. In such engines, however, the pressure is relieved during the second stroke. This enables the oil to spread over the cylinder liners more readily and facilitates the sliding action of the pistons and rings during the subsequent strokes of the cycle.

Relation of Piston Seal to Oil Film Maintenance

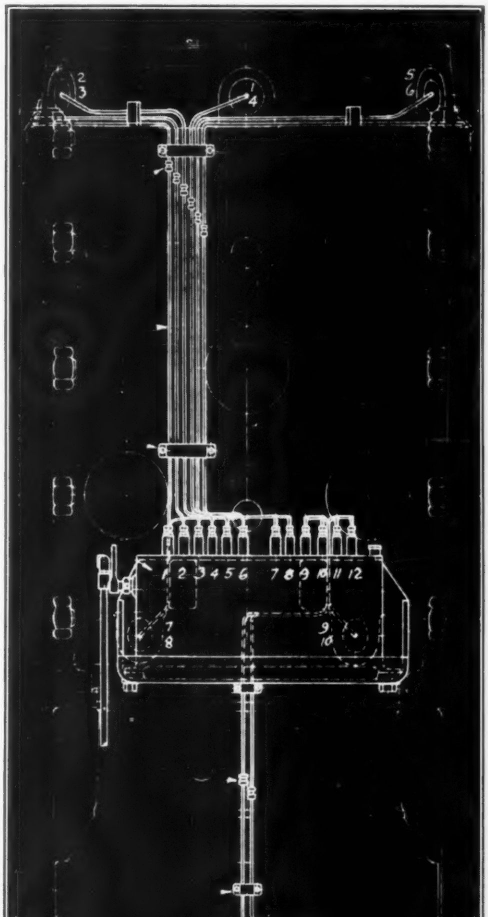
In the Diesel engine, piston rings in conjunction with a suitable sealing medium in the form of a lubricating film, serve to maintain a seal and prevent leakage of the high pressure gases past the pistons. Leakage, of course, would mean reduced efficiency. Although the metal surfaces of cylinders, pistons, and rings are carefully finished and accurately fitted, leakage of gases cannot be prevented unless the small openings between the wall and rings are effectively sealed by the lubricant.

By virtue of the laws of friction, metal surfaces rubbing one over the other will generate excessive heat and produce abrasion of the materials. This can be partly eliminated if the surfaces are separated and free motion permitted by means of a suitable fluid medium. Thereby metallic friction is replaced by less severe fluid friction, wear is reduced, and an adequate lubricating film is provided to aid the piston rings in sealing the piston. All this will result in greater unit power development per gallon of fuel consumed.

As already stated, however, the lubricating oil film must be maintained under two distinct conditions of operation, i.e., high temperature and high pressure. The higher the temperature of the products of combustion, the hotter will be the adjacent parts, with consequent reduction in the body of the oil film separating the metal surfaces. The greater the gas pressure, the more difficult will it be to maintain a lubricating film between the rubbing surfaces. The upper piston rings, especially, will be called upon to bear the brunt of these operating conditions.

Relation of Pressure to Oil Film Formation

The duty of an oil film with respect to cylinder pressure is to reduce leakage or blowby as far as possible, particularly under conditions of rapid increase in pressure during the compression stroke, when a maximum of perhaps 600 lbs. per sq. in. will be reached in the cylinders of some engines. Under such pressures the gases will tend to escape past the split of each piston ring as well as past the clearance between each ring and its groove. This causes pressure to build up behind the rings. The highest pressure is, naturally, behind the uppermost ring, being nearly as great as that on the piston head itself; there is a gradual decrease in pressure behind each succeeding ring, however, until it becomes



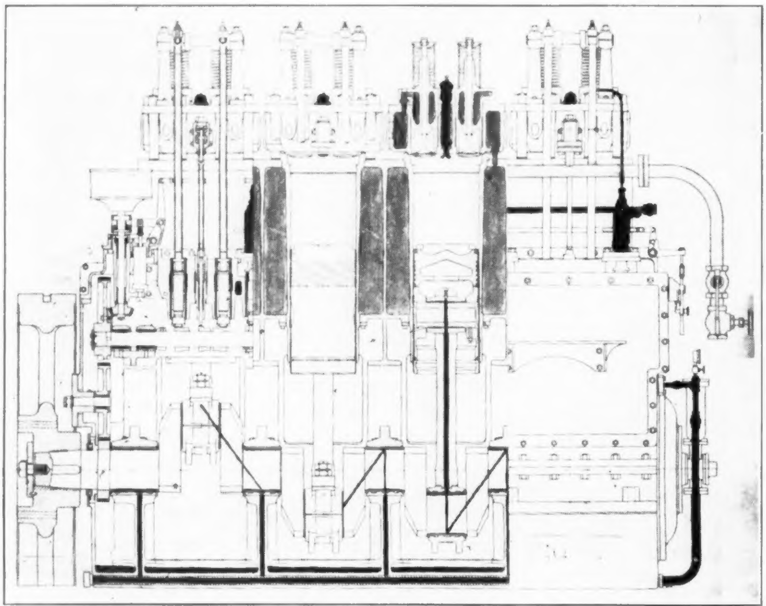
Courtesy of Hooven, Owens, Rentschler Company

Fig. 2—General arrangement of means for cylinder lubrication for a Hooven, Owens, Rentschler Diesel, showing respective oil leads from the lubricator. Inlets 1, 2, 3, 4, 5, and 6 serve the upper part of the cylinder; inlets 7, 8, 9 and 10 the lower part, and inlets 11 and 12 the stuffing box.

practically negligible behind the lowest ring at the bottom of the piston.

The tendency of such pressures to force the rings nearest the top of the piston against the cylinder wall, produces a squeezing action which

the lubricating oil film must support. The oil film, therefore, performs a dual function, being not only depended upon to support the pressure of the rings, but also to seat them effectively against blowby during the compression and power strokes.



Courtesy of Worthington Pump and Machinery Corp.

Fig. 3—Oiling diagram of a Worthington Model D vertical 4 cycle direct injection engine. Heavy black lines on the top side of the engine indicate fuel; similar lines at the base of the engine and extending through the connecting rod indicate lubricating oil; gray portions indicate provisions for water cooling.

Proper installation of piston rings will have a marked influence upon oil consumption. In instances where sharp edged types of scraper rings are used, it is important to make sure that they are not installed upside down. Otherwise an excess of lubricating oil consumption, particularly in trunk type engines, may develop.

Cylinder Temperatures

High temperatures prevail in Diesel engine cylinders, by reason of the fact that a large portion of the cylinder wall over which the piston passes is swept by flame every stroke in a two-cycle engine and every other stroke in a four-cycle engine. The initial temperature of this flame is at least 2000 deg. Fahr., ranging up to a maximum in the neighborhood of 2700 deg. Fahr., according to the type of engine. Obviously no lubricating oil film could stand exposure to such temperatures, regardless of its refinement.

Fortunately, however, such temperatures prevail for only a short time, decreasing from the maximum as expansion and exhaust of the burning charge take place. There is then a gradual rise during the compression stroke. The minimum temperature is in the neighborhood of 250 deg. Fahr., while the average during a complete cycle is probably about 950 deg. Fahr. These temperatures pertain to the gases, however, and not to the cylinder walls. In the latter it is extremely difficult to obtain more than an indication of the actual metal surface temperature, even by use of thermocouples.

As long as the circulating water is not boiling it is safe to assume that the cylinder wall temperature is not above 250 deg. Fahr., and the temperature of the piston not many degrees higher. Therefore, with proper cylinder and piston cooling, the high temperature of the gases should not cause any alarm. Furthermore, oils suitable for Diesel engine cylinder lubrication will normally have a flash point above 350 deg. Fahr. In other words there is a factor of safety of at least 100 degrees.

Lubricating oil does not burn readily and furthermore the time in the cylinder is short. An engine running at only 100 r.p.m. would expose the lubricated surface of the cylinder to the action of the flame for only a fraction of a second. At higher speeds the time of exposure is so much shorter that a considerably lower flash point would probably lead to no abnormal lubricating oil consumption.

Adequate cooling of the cylinder walls by water circulation through jackets is the secret of reduced temperatures and the maintenance of proper lubrication. On the other hand, the time element in connection with the rapid reciprocating movement of the pistons furnishes intermittent protection and carries fresh oil from the cooler parts to those subjected to higher temperatures.

In single acting Diesels the highest cylinder wall temperatures are, of course, at the top, decreasing towards the bottom. In double acting engines both ends of the cylinders are subject to high temperatures, the decrease being toward the center. The operating factors which govern the actual temperatures of the cylinder wall surfaces include the temperature, velocity and the quantity of cooling water, the quantity of heat necessary to be conducted per unit of area through the cylinder walls, the diameter of the cylinder, the thickness of the liners, and the load developed.

Characteristics Essential to Proper Cylinder Lubrication

Inasmuch as combustion in Diesel cylinders gives rise simultaneously to high temperatures and pressures, the possible detrimental effects, especially under adverse conditions, must be fully realized. The results may include abnormal reduction in the viscosity of the oil film, loss of compression and excessive cylinder liner wear, increase in power and upkeep costs, and high oil consumption.

Under such conditions of high pressure and temperature the lubricant must be able to spread rapidly on the cylinder walls and to replenish its own lubricating film. It must show adequate film strength, especially when exposed to high combustion temperatures as well as the pressures to which it is subjected through the piston rings. Furthermore, it must maintain a virtually complete piston seal under all conditions.

Cylinder liner wear, which is the direct result of impaired lubrication, is generally greatest at the combustion ends of the cylinders, i.e., in the vicinity of the upper piston rings, where maximum temperatures and pressures exist. The wear decreases along the cylinder walls in proportion to the lower temperatures and pressures encountered during the power stroke.

An oil to meet these requirements must show a low carbon residue and an ability to resist breakdown under high temperatures and pressures. Low carbon residue insures clean cylinders, freedom from carbonized rings, and proper functioning of the valves. Extensive research has indicated that oils possessing this outstanding characteristic will insure engine operation with minimum wear, low oil consumption, and reduced repair costs.

Effect of Cylinder Size

Increase in cylinder diameter may have an effect upon the performance of the lubricating oil film, by reason of the probable increase in cylinder wall temperatures due to increase in radiant heat.

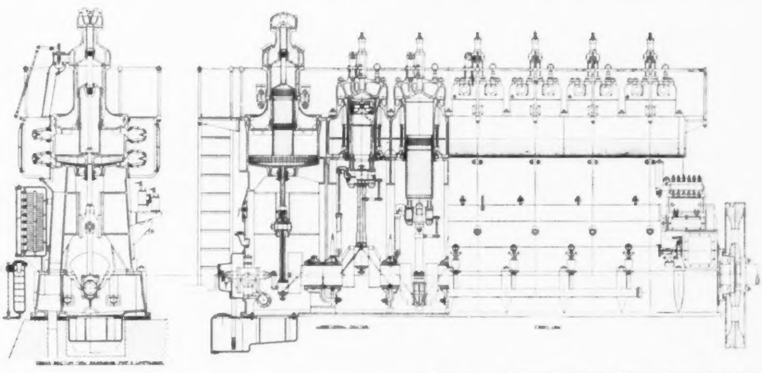
For this reason, small bore cylinders are more easily lubricated. Although the cylinder wall area increases only as the bore so that the heat conditions might not at first be considered serious for large bores, they do become more so as the size increases. This is indicated both by increased lubrication and cooling difficulties, in actual operation.

The amount of heat liberated increases as the square of the diameter and the greatly increased heat effect is probably due to radiant dissipation of heat. This is felt to be a very important factor in heat loss from the burning charge to the walls. Due also to the unavoidable greater thickness of cylinder liners in larger engines, the temperature difference between the cooling water and the gases in the cylinders will tend to increase. Furthermore, increased cylinder wall thickness tends to reduce the heat absorbed by the cooling water, and therefore, augments the temperature of the oil film. In view of the generally higher oil film temperatures in engines of large cylinders, a somewhat higher viscosity oil is essential for efficient lubrication, and ultimate economy. Increased viscosity will also aid in decreasing the loss through vaporization.

CHARACTERISTICS OF BEARING OILS

The durability of bearing oils may be said to be influenced by their ability to separate from water, their heat resisting and absorbing qualities, their resistance to formation of gummy residues, their ability to maintain as nearly as possible their original viscosity, and their resistance to oxidation.

Separation from water is essential in the interest of preventing emulsification and subsequent formation of insoluble sludges. Obviously these latter might frequently accumulate in oil grooves or distributing piping to impair circulation of the oil. Under aggravated conditions this might lead to bearing troubles and excessive wear, due to delivery of an insufficient amount of oil. Sludge formation might be expected to be particularly serious in systems where the volume of oil in circulation is small, and where it must perform its duty without time for adequate cooling and precipitation of suspended impurities.

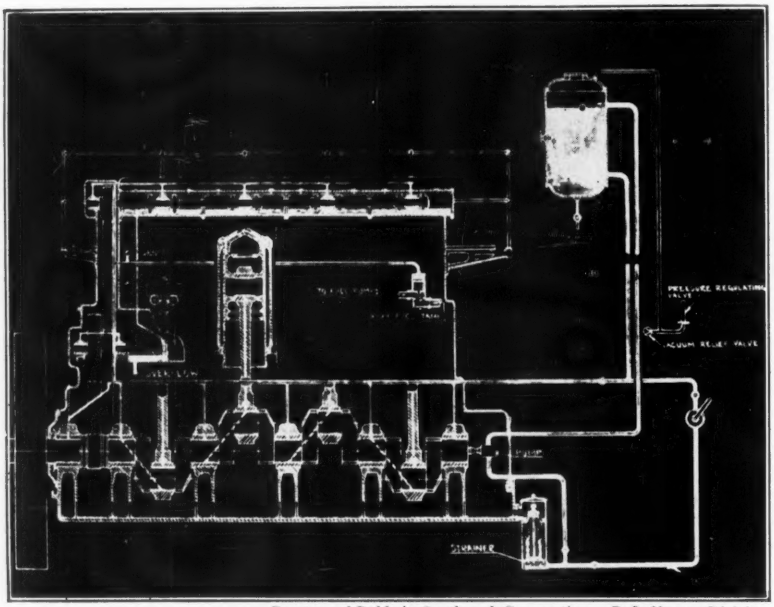


Courtesy of The Nordberg Manufacturing Co.

Fig. 4—Longitudinal section and end view of a Nordberg NF Type Diesel engine. Note provision for oil circulation to bearings, via drilled crankshaft and connecting rods.

Heat resisting ability is necessary, particularly in engines of the trunk type where the cylinders are directly connected and open to

the crankcase. Radiation of heat from the pistons in such cases will often be comparatively high. Its subsequent transmission to certain of the bearings requires that the oil be capable of not only functioning as a cooling medium



Courtesy of Baldwin-Southwark Corporation,—DeLaVergne Division

Fig. 5—Lubricating oil system for DeLaVergne Type VG, VA, VF, and VB Diesel engines, showing relative location of oil pump, strainer, pressure regulating valve, vacuum relief valve and over-flow. Note provisions for complete automatic circulation.

but also of resisting breakdown and oxidation. Development of these latter would naturally lead to loss of more or less oil from the system, but the more serious problem would be oxidation with ultimate formation of sludges and gummy residues.

Maintenance of original viscosity as nearly as possible indicates adequate refinement and ability of an oil effectively to resist breakdown. Viscosity is of particular importance in gravity circulation systems, for increase in viscosity to such an extent as to cause sluggish flow under reduced external temperatures might readily lead to bearing troubles due to lack of sufficient oil.

Positive pressure circulation is for this reason more dependable in the handling of crankcase oils. On the other hand, pump operations must be carefully watched to prevent excessive churning and aeration, for subsequent atomization might increase oxidation and lead to reduced life of the oil. High pumping pressures may often be the cause of atomization, as the oil is forced through the bearing clearances. This may be a serious factor in higher speed engines where limited oil supply is available, and where comparatively high bearing pressures have influenced raising the oil pressure in order to insure more positive maintenance of the lubricating film.

Crankcase Lubrication

Diesel engine crankcase lubrication involves the main crankshaft bearings, as well as those of the connecting rods, wrist pins, crosshead, and auxiliary elements such as timing gear connections. When to change a Diesel crankcase oil is an important problem to all operators. At first sight the problem would seem to be quite similar to the automotive engine. When one considers the difference between the types of operation and the numerous factors which may affect the lubricating value of any oil it can be realized that to set forth any arbitrary rule would be impossible. The all important point is to watch the physical and chemical properties of the oil through the medium of periodic analysis. Particular attention should be given to abnormal change in viscosity, development of carbon residue above the indicated limits as specified by the engine builders and manufacturers of Diesel lubricating oils, and the tendency toward high acidity.

Effect of Oxidation

Oxidation in its occurrence in a Diesel engine is due to the gradual absorption of oxygen by the oil in circulation. It is indicated by development of brownish sludge. The greater the surface of oil exposed to the air and thus to its oxygen content, the greater may be the ultimate chemical reaction of oxidation. To appreciate the extent to which a film of lubricating oil may be expanded from a surface viewpoint, it is well to visualize its course through the engine bearings.

In a pressure circulation system the oil enters the bearings to form a wedge shaped oil film. Upon its escape from the ends of the bearings, it is thrown violently about in the crankcase and broken up into fine spray due to the action of the revolving crankshaft.

Oxidation of this fine oil spray is accelerated by the hot air in the crankcase, especially in the presence of water and other impurities. The ultimate result under constant churning is emulsification with subsequent permanent sludge formation.

Obviously this will occur to a widely varying degree, dependent upon the original refinement

of the oil, its resistance to oxidation and emulsification, the temperature of the crankcase, the manner of ventilating this latter, the amount of oil in service, and the speed of the engine.

To attempt to predict the probable life of any oil under such a wide range of constructional and operating conditions, would be hazardous. Best procedure in modern practice is to subject the oil to periodic analyses as mentioned above.

Amount of Lubrication Required

The quantity of oil which should be circulated through a bearing lubricating system varies widely, according to engine design and the means of lubrication. It is largely dependent upon the size and speed of the unit as well as the design of the lubricating system. The chief requirement is that the amount of oil circulated shall be considerably in excess of what is actually necessary for lubrication, to enable the volume of oil flowing through the bearings to serve as a cooling medium in addition to maintaining a film between the bearing surfaces. Properly refined lubricants will not break down under such arduous service and will readily carry the prevailing pressures, serving as well as decidedly effective cooling media. In regard to this latter, however, it must be borne in mind that heat transfer ability will vary directly as the viscosity.

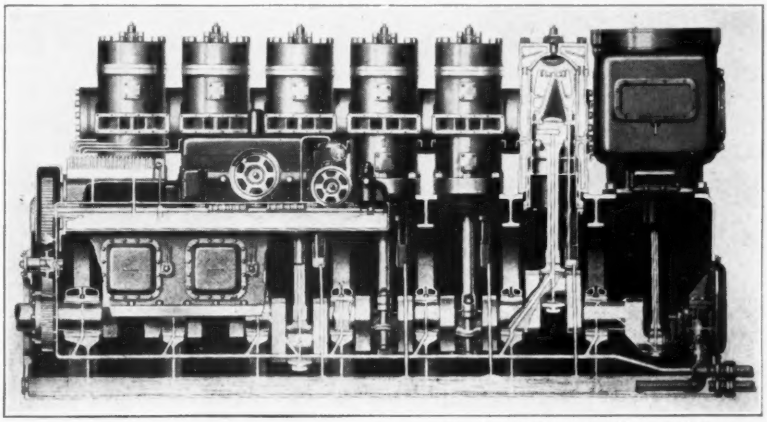
Film Formation

When a shaft at rest starts to revolve, the lubricating oil adhering to the surface is drawn in between it and the bearing, to form a wedge in the pressure area, being accelerated by the pressure on the oil. The bearing serves as an effective auxiliary oil pump in this respect. If the velocity of the rotating element is low, especially if the oil is fairly heavy, it is very possible that a complete oil film may not be formed immediately. It is claimed, however, that with a velocity as low as ten feet per minute oil is drawn into the clearance space to form such a wedge. As this wedge of oil forces the shaft over, its center is raised to a position more in line with the center of the bearing, to eliminate actual metallic contact. As the velocity increases, the thickness of the oil film becomes more uniform and the center of the shaft approaches more closely to the center of the bearing. If the load be increased, however, beyond the carrying ability of the oil film as the speed is kept constant, the journal will tend to approach a point on the bearing where the oil film will ultimately be ruptured with resultant friction, wear, and possible breakdown of the unit.

Effect of Viscosity

The extent to which the oil film in a plain bearing will resist the prevailing squeezing action which is developed during rotation will be dependent upon the body or viscosity of the oil in circulation, the size, clearance, and especially the smoothness of the engine bearings; the speed of rotation, the unit pressure exerted upon the bearing, and the temperature of the oil.

Under conditions of starting, or in the case of slow reversal movement as with piston pin or crosshead bearings, the formation of an oil wedge and maintenance of an oil film are less readily effected than in higher speed elements. There is, therefore, a greater tendency for the oil film to be squeezed out of the pressure area. With heavier or more viscous oils a thicker lubricating film is produced. For this reason it is more difficult to squeeze out such oils from between bearing and shaft surfaces. On the other hand, there may also be difficulty in drawing such oils into the bearing clearances, due to their natural cohesiveness and lower fluidity. Such oils are used where bearing pressures are high, the clearances large, or high temperatures of operation prevail. Of course, if too heavy an oil is selected for a certain service, the fluid friction and bearing temperature may become excessive and separation from the inevitable impurities gathered during circulation through the oiling system may be difficult.



Courtesy of Fairbanks, Morse and Company

Fig. 6—Longitudinal section through a Fairbanks Morse Diesel Engine, illustrating pressure circulating system for lubricating and cooling the oil.

Dependent upon the size of the engine, with increased speed it may be practicable to reduce

the viscosity, especially where crankcase operating temperatures can be controlled, for less internal friction will be developed when the oil film is subjected to the higher rubbing speeds which prevail in the majority of the bearings. Use of a lighter bodied oil will also be conducive to lower bearing temperatures. In high speed bearings the bearing pressure may also be lower. This also permits use of a lower viscosity oil. It is important to remember however, that if too light an oil is used, the lubricating film may not possess sufficient body to keep the metal surfaces apart. This would cause rapid wear and result in burned out bearings. As such an oil is readily atomized on escaping from the bearings, the spray thus formed in intimate contact with air promotes oxidation. Excessive lubricating oil consumption may also result from the use of too light an oil, according to engine design, operating conditions, and possibility of oil leakage.

OXIDATION

Among the factors which may influence the durability of a Diesel oil, oxidation requires serious consideration. Mineral oils will be subjected to more or less oxidation when agitated under higher temperatures in the presence of air and water.

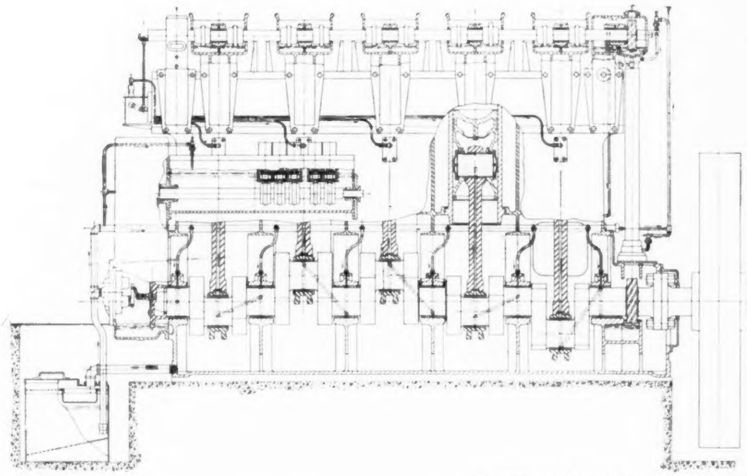
These conditions are normally so involved and so contingent upon one another that no one of them can be rightly claimed as being more detrimental than the other. On the whole, however, it may be stated that the extent to which oxidation will occur depends largely upon the refinement of the original oil. In other words, certain petroleum hydrocarbons will probably oxidize more readily than others.

Logically, therefore, it would be advisable to bend every effort in the refinery to effect the removal of these components by careful and accurate refining. The more reliable the manufacturer, naturally the more dependence can be placed on his methods of refining.

Oxidation will, of course, occur in practically any oil if it is subject to oxidizing conditions. In fact, wherever particles of air and water are suspended or retained within the body of an oil to form an emulsion, only a slight elevation of temperature during circulating or agitation will be necessary to bring about an oxidizing reaction between the air and oil.

Metallic Particles a Factor

Oxidation, furthermore, is aided by metallic particles, especially brass, copper, and iron, or other foreign matter, such as dust and dirt. In fact, in an already emulsified oil foreign matter of this nature is regarded as being the co-partner of oxidation in producing the resultant insoluble sludges so detrimental to proper lubrication.



Courtesy of Fulton Iron Works Co., Inc.

Fig. 7—Sectional view of a Fulton Diesel engine, indicating the path followed by lubricating oil through crankshaft and connecting rods. All bearings, as well as cam shaft gears, are lubricated by a positive circulating pressure system. Oil drains from the crankcase into one of two sump tanks, where it is strained prior to recirculation.

It is believed by some that if emulsification is prevented, sludging will be greatly lessened. But the former involves only oil and water. It would, therefore, seem logical to consider foreign matter, or the catalyzers such as metallic particles which promote oxidation, as an equal detriment.

Emulsions alone are certainly not so viscous, adhesive and generally objectionable as insoluble sludges which so frequently clog oil passages, congest the oiling system, and generally reduce the lubricating quality of the oil. The natural procedure is, therefore, to reduce the effect by removing the cause as far as possible; in other words, by purifying the oil during operation to a sufficient degree to keep down the percentage of water, emulsion and foreign matter.

Acidity

The relation which acidity bears to emulsification and sludge formation has been the basis of considerable study on account of the extreme complexity of the acid-forming constituents and the limited knowledge of their reactional tendencies. In this connection it is interesting to note that the oxidation products or petroleum acids are not corrosive as a general

rule but may be instrumental in the formation of sludges.

For this reason every effort is made in refinement to render oils as chemically stable as possible. The most careful attention to the oils throughout the process of refining should always be observed. But no process renders an oil non-reactive when it is subjected to detrimental conditions in the presence of air and water under high temperatures.

Dust and dirt are in turn always present in the air to a certain extent, wherever the oil is in passage. Therefore, it is logical to expect that foreign matter of this nature will find its way into the oil, not only to cause abrasion and corrosion, but also to act in the same catalytic manner as metallic particles.

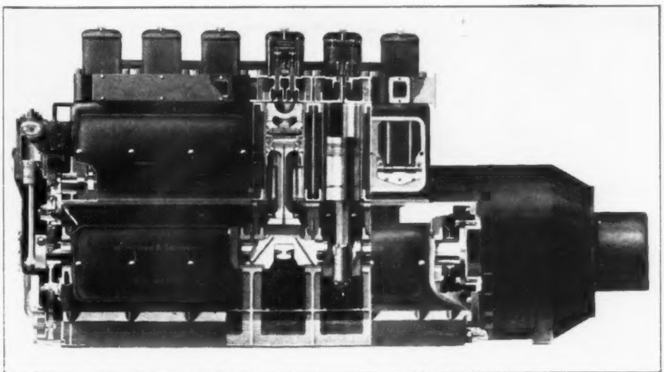
Acidity as Determined by Neutralization

In view of the potential acid characteristics of any petroleum lubricant in service, the acidity has come to be regarded as an important factor, especially in a study of Diesel engine lubrication. In this case, it must be borne in mind that mineral acidity which develops in use may be particularly detrimental, for it is almost invariably the prelude to sludging.

Acidity is measured by The Neutralization Number, which, according to the definition of The American Society For Testing Materials, is the weight in milligrams of potassium hydroxide required to neutralize one gram of oil.

INCOMPLETE COMBUSTION AND CARBONIZATION

In the operation of the Diesel engine the development of carbon residue will be brought about in very much the same manner as in the automotive type of internal combustion engine, in view of the comparatively high temperature to which both the lubricant and fuel are subjected. In the Diesel engine, however, there is more possibility of development of carbon residue from incomplete combustion of the fuel than in the automotive engine. The average grade of fuel oil, being very often partly or entirely of a residual nature, will have a higher percentage of certain hydrocarbon constituents, which will break down more readily and develop carbon residue.



Courtesy of McIntosh and Seymour Corp.

Fig. 8—Cutaway view of a McIntosh and Seymour "Alco Type" Diesel railway engine. Force feed lubrication is used throughout.

Imperfect or incomplete combustion, therefore, requires detailed consideration, due not only to the extent to which it may develop carbon residues, but also the degree to which it may affect fuel economy in general.

Incomplete combustion is the result of low compression pressures, caused either mechanically or by leaky rings, excessive overloads or an improper mixture.

Where incomplete combustion is allowed to continue, carbonization will practically always occur, especially on the piston head and in all probability around the rings. Therefore, carbonization is often the cause of faulty valve action and stuck piston rings. In turn, this latter occurrence will cause compression losses.

In consequence, a complete cycle of inefficiency may result. Where rings are stuck in their grooves they must be loosened as soon as possible. Oftentimes kerosine or a lye-water mixture will serve this purpose, cutting the gummy matter effectively, in case merely scraping away the deposits is not sufficient.

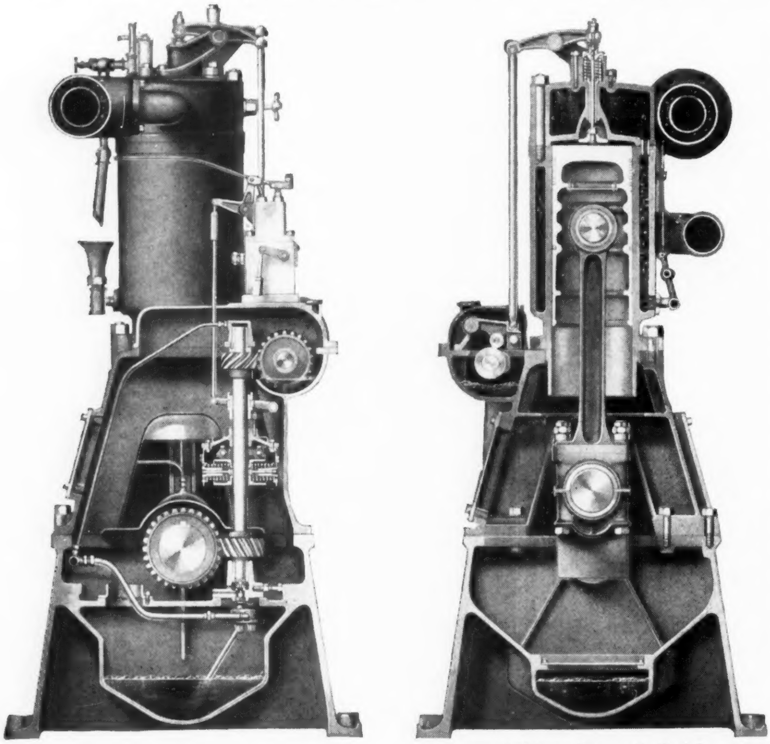
Diesel Engine Air Compressor Requirements

The air compressor in Diesel service requires careful consideration due to the part it plays in bringing about combustion. It will be extremely important to note the effect which carbon deposits may have upon the efficiency of operation of such a compressor.

The air compressor as usually installed in higher powered Diesel engines will generally have either three or four stages, and will be equipped with suitable intercoolers. The compression of air to pressures in the neighborhood of 1,000 pounds will, of course, develop a considerable amount of heat; it is the function of the intercoolers to reduce this heat and thereby keep cylinder temperatures down, thus minimizing the extent of oil vaporization. This is, of course, in the interest of safety, for otherwise accumulations of dust and carbonaceous matter in the intercoolers, etc., might easily so restrict the air passages as to increase the velocity and consequently the frictional temperature of the air to such an extent as perhaps to cause mechanical failure in some part of the system.

Deposits of Dirt and Carbon

While dirty air is perhaps one of the most general causes of such accumulations of foreign matter, we must not forget that an excessive amount of lubricating oil will also tend to develop carbonaceous matter which will materially increase the accumulation of deposits.



Courtesy of Chicago Pneumatic Tool Company

Fig. 9—Sectional views of a Chicago Pneumatic MWM Benz Diesel engine, showing lubricating oil pump as well as valve operating mechanism.

In addition, an excess of oil fed to the compressor cylinders may bring about leaky valves due to a certain amount of oil becoming carbonized on the latter. All this, of course, leads to a decrease in operating efficiency, for this carbonaceous matter, being relatively sticky in the early stages of its formation, will tend to adhere to the piston rings, thereby causing them to become inoperative; furthermore, it will tend to destroy the lubricating film and result in scored cylinders.

Unfortunately, there is no oil which will not deposit some carbon; on the other hand, there is a surprising difference in the nature and quantity of this carbon which will be developed by different oils. Consequently, not only must an oil be most carefully selected, but also, whatever its characteristics, the utmost care should be taken to prevent the use of more oil than is necessary.

In this respect, it is very difficult for some operators to realize that but one or two drops of oil per minute is all that is necessary. This is effectively counteracted in many Diesel air compressors by so designing that the intermediate stage is at the bottom. As a result of such construction there is always a pressure opposing the tendency of the oil to work up into the air space from the lowest cylinder wall where it may be thrown by the crank pin.

Nature of Carbon Developed in Service

As has already been stated, carbon is an essential element in the make-up of any petroleum product. It must, however, be present in more or less intimate chemical combination with hydrogen. There is a distinct difference between carbon as it exists in this manner and carbon as it is found in actual operation in the form of coke or carbon residue. In the former instance, the complex hydrocarbons involved have a high degree of oiliness. They have, therefore, proved themselves as most adaptable lubricants. Coke or carbon residue developed as a result of break-down of certain of these hydrocarbons under high temperature, however, has no lubricating value whatsoever. In fact, the resultant material is even a particularly poor grade of carbon. The nature of this latter from a physical point of view will depend upon the base of the crude from which the lubricant has been refined.

As a result, carbon residue as it appears in the operation of the internal combustion engine or the air compressor will be found to vary widely in its degree of hardness and adhesiveness. Whatever its residual form, however, it is always important to remember that carbon, as it results from the break-down of any lubricating oil, is not a lubricant and therefore may develop into a decided abrasive and do a considerable amount of damage to bearings.

It may also accumulate around the piston rings in an internal combustion engine and prevent free operation of these elements. The extent to which this latter may occur, or in fact, accumulation of any excessive amount of carbon residue in such an engine, will depend on the base of the crude, and the degree of refinement. In this connection, it is interesting to note that well refined naphthenic base oils have been found to give a carbon residue of a comparatively soft, fluffy nature, which nor-

mally can be easily removed by brushing. It is reasonable to presume that carbon of this nature will oftentimes be very largely removed from the Diesel engine, for example, by the exhaust before it has a chance to accumulate within the engine.

On the other hand, certain paraffin base oils, if not properly refined, will develop a carbon residue which will be of a comparatively hard and adhesive nature.

Indications of Carbon Accumulation

Accumulation of carbon deposits in the Diesel engine will be primarily indicated by loss of power, just as holds true in any other type of internal combustion engine.

In the Diesel engine, however, there is not the same tendency to develop knocking, due to the manner in which the fuel is burned. As a result, it will be essential for the operator to pay more attention to the power out-put. This of course, is more easily accomplished in connection with such an engine, in view of the fact that it is stationary and therefore readily adapted to the installation of power measuring instruments.

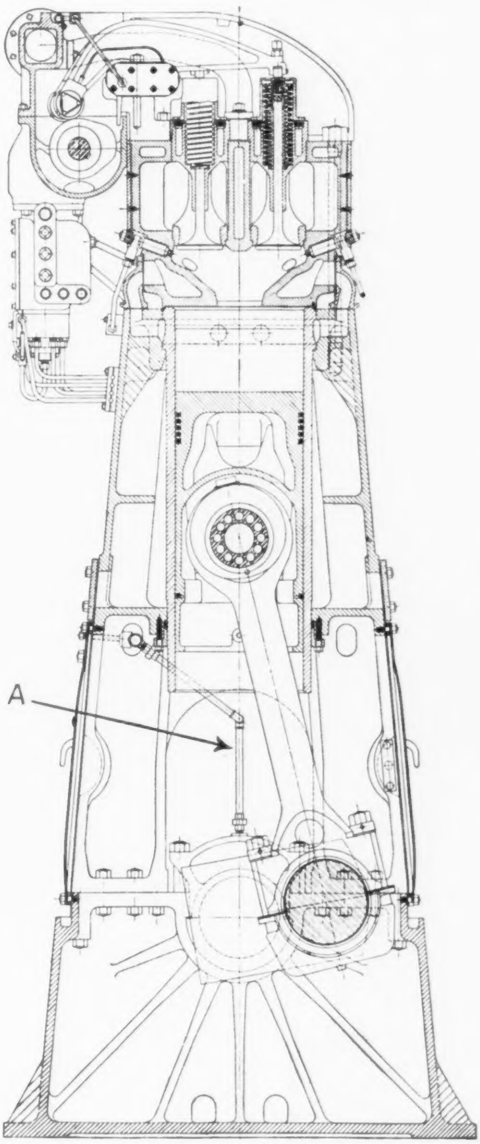
RELATION OF VISCOSITY

Consideration of viscosity as a factor in the selection of lubricants for Diesel service will be of interest. Viscosity being a measure of the relative fluidity of a lubricant is indicative of the body of the latter. Practically speaking, this means its ability to withstand the squeezing out effects of pressure by virtue of the cohesion between its component molecules.

Temperature and Pressure Effects

Where high operating temperatures may prevail the proper viscosity or body of a lubricant must be given all the more careful attention, for viscosity will vary inversely with temperature. In other words, the higher the operating temperature the greater will be the tendency for the body or viscosity of the lubricant to be reduced. If the original viscosity is not sufficiently high to allow for this reduction, the increased fluidity may lead to impairment of the lubricating film to such an extent as actually to cause metal-to-metal contact.

This will be especially apt to occur under comparatively high pressure. It is for this reason that the viscosity-temperature conversion chart should be studied in connection with the formulation of a lubrication recommendation for Diesel engine operation. By the use of such a chart one can readily determine the operating viscosity of any lubricating oil at the prevailing temperature of operation, knowing the viscosity at some two points such as 100 degrees and 210 degrees Fahr., according to the prevailing marketing specifications. Normally lubricating oils of a viscosity up to approximately 800 seconds Saybolt at 100 degrees Fahr., are specified at this particular temperature. The viscosity of heavier lubricants,



Courtesy of Ingersoll-Rand Company

Fig. 10—Cross section of a solid injection, 4 cycle Diesel engine. "A" indicates oil lead to main bearings, oil being supplied under positive pressure from a gear type pump.

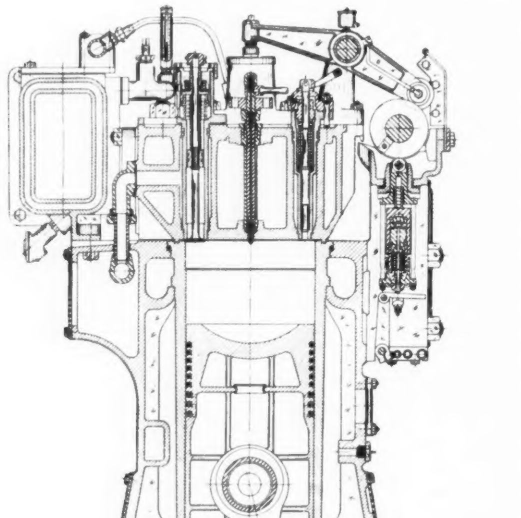
however, is usually stated at 210 degrees Fahr.

While the use of an oil of sufficient viscosity to meet the operating conditions will, of course, result in more effective lubrication, it will also prove of decided value in reducing the amount of power or energy required to move the working elements. In addition, any tendency toward the development of abnormal frictional heat will be reduced.

All this will lead to improved lubrication, for it will enable the oil to perform its function

more perfectly, maintaining the proper lubricating film under all conditions, by virtue of its viscosity or body.

It has already been stated that viscosity varies inversely with the temperature. In Diesel



Courtesy of The Cooper-Bessemer Corp.
Fig. 11—End sectional view through a Cooper-Bessemer Diesel engine showing constructional details and provisions for lubrication.

service this is an asset, for it enables one lubricant to serve a number of points of varying external temperatures, provided the size of the wearing elements and the pressure exerted are taken into account when the lubricant is originally selected.

On the other hand, the mistake should never be made of regarding the viscosity at say 100 degrees Fahr., as of sole importance, for an oil which might be of adequate viscosity at that temperature might be too light to meet an operating temperature range at say 150 degrees Fahr. There is, therefore, a direct tie-up between power consumption, friction, and temperature.

Viscosity Defined

Inasmuch as "operating viscosity" plays so important a part in this matter of Diesel engine lubrication, a detailed knowledge of viscosity in general will be advisable. Just what is meant by the statement that an oil should have a viscosity of let us say 500 seconds Saybolt at 100 degrees Fahr., will be vague to many. It is well, therefore, to mention that this means at a uniform temperature of 100 degrees Fahr., it will take 60 c.c. of the oil in question 500 seconds to flow through the orifice of the standard Saybolt universal viscosimeter.

As a result, viscosity is an indication of relative fluidity of an oil at the temperature of test. In brief, it is that inherent property by virtue of which the flow of liquids is retarded, through the resistance offered by the particles or molecules of a liquid in sliding past each other. It is therefore possessed by all oils in varying degrees.

CONCLUSION

By reason of the wide range of conditions which may affect the durability and rate of consumption of Diesel engine lubricating oils, particularly those in crankcase service, it is virtually impossible to make any general prediction as to the probable effective life, or to suggest any time limits in regard to oil change. Practically every installation requires individual study, with due consideration of the operating and constructional conditions. Ultimately a basis can be arrived at, provided such observations have been extended to cover laboratory study of the physical and chemical condition of the oils in service. Then only should an estimate be made covering the rate of time which should elapse between oil change.

Laboratory study of lubricating oils in service, as already stated, should be particularly concentrated upon development of oxidation as indicated by acidity, change in viscosity and increase in carbon residue content. Safe limits in this regard would be an acid or neutralization number of perhaps 2.0, an increase in viscosity not to exceed 20 percent, and a Conradson carbon residue of 1.5 maximum. Obviously these figures can only be quoted as generalities for they might require marked revision either way depending upon specific installations and types of oils.

Printed in U. S. A. by
Edgar C. Ruwe Co., Inc.
72 Washington St., N. Y. C.